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SINGLE-VALVE PROTOTYPE TESTS, MAIN LOCK, LOCKS AND DAM 26, MISS--ETC(U)
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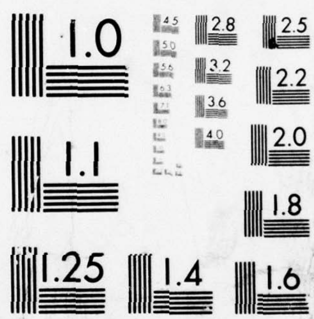

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SINGLE-VALVE PROTOTYPE TESTS, MAIN LOCK LOCKS AND DAM 26, MISSISSIPPI RIVER ALTON, ILLINOIS

by

E. Dale Hart

Hydraulics Laboratory
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P. O. Box 631, Vicksburg, Miss. 39180

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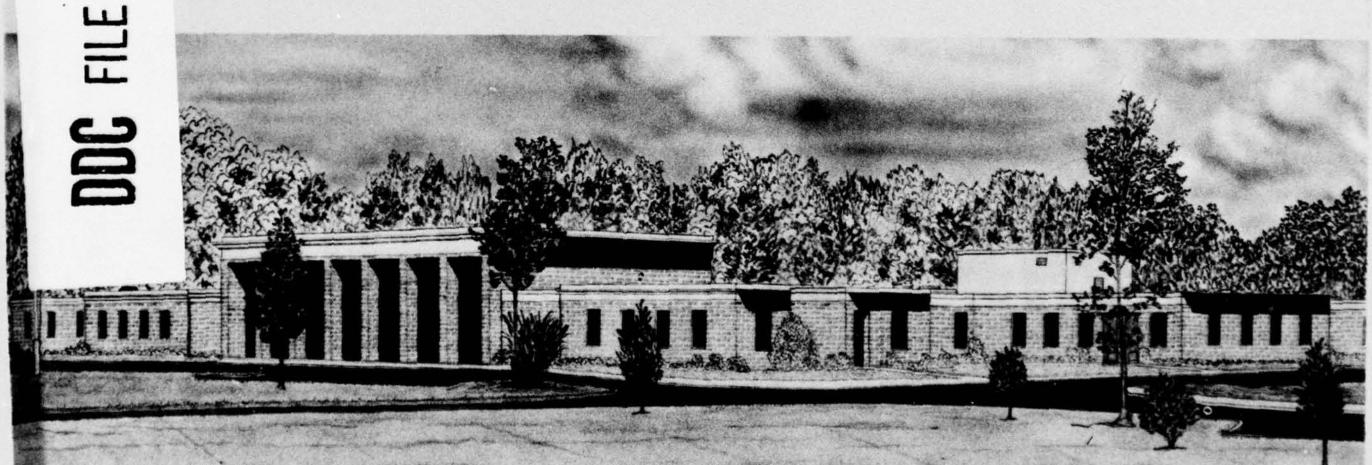

Prepared for U. S. Army Engineer District, St. Louis
St. Louis, Missouri 63101

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Lock filling and emptying systems
Prototype tests

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Prototype tests were conducted to determine the fastest permissible single-valve lock chamber filling (and emptying) that could be tolerated without exceeding the generally accepted maximum load per hawser of 5 tons. A number of filling valve openings were used while hawser loads and other phenomena were measured. As a result, initial filling valve opening of 3.4 ft (20 sec) was recommended. No restrictions on the emptying valve opening were found to be necessary.

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PREFACE

The prototype tests described in this report were conducted during July 1977 by the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Army Engineer District, St. Louis.

Acknowledgment is made to the individuals of the St. Louis District, especially Mr. Jim Fogilphol, Lockmaster of Locks and Dam 26, for their assistance in this investigation. Mr. E. D. Hart, Chief of the Prototype Branch, was test coordinator for WES. This report was prepared by Mr. Hart under the general supervision of Mr. E. B. Pickett, Chief of the Hydraulic Analysis Division, and Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, WES.

COL John L. Cannon, CE, was Commander and Director of WES during the investigation and the preparation and publication of this report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	metres
feet per second	0.3048	metres per second
inches	25.4	millimetres
inches per second	2.54	centimetres per second
miles (U. S. statute)	1.609344	kilometres
pounds (force)	4.448222	newtons
pounds (force) per square inch	6894.757	pascals
tons (force)	8896.444	newtons

SINGLE-VALVE PROTOTYPE TESTS, MAIN LOCK
LOCKS AND DAM 26, MISSISSIPPI RIVER
ALTON, ILLINOIS

PART I: INTRODUCTION

Background

1. Locks and Dam 26 have been the subject of numerous investigations of navigation improvements. Both replacement and alteration of the existing structures have been considered. Included is a plan which requires closure of the land-wall filling and emptying culvert of the main lock for an extended period of time in order to further stabilize the wall. The U. S. Army Engineer Waterways Experiment Station (WES) was requested to determine the hawser forces that would occur during the resulting single (intermediate wall) culvert filling and emptying necessitated by the plan.

2. The project shown in Figure 1 is located at Mississippi River mile 202.9, adjacent to Alton, Illinois. This location is approximately 20 miles* north of St. Louis and lies between the mouths of two major tributaries--the Illinois River, 15 miles upstream, and the Missouri River, about 8 miles downstream (Figure 2).

Pertinent Features

3. The project has two locks (main and auxiliary) and a gated dam. The 1725-ft-long dam contains thirty 40- by 30-ft tainter gates and three 80- by 25-ft roller gates. The main lock chamber is 110 by 600 ft and the auxiliary, 110 by 360 ft. Maximum project lift is 24.0 ft with the upper pool elevation at 419.0** and lower pool at 395.0, minimum

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

** All elevations (el) cited herein are in feet referred to mean sea level.

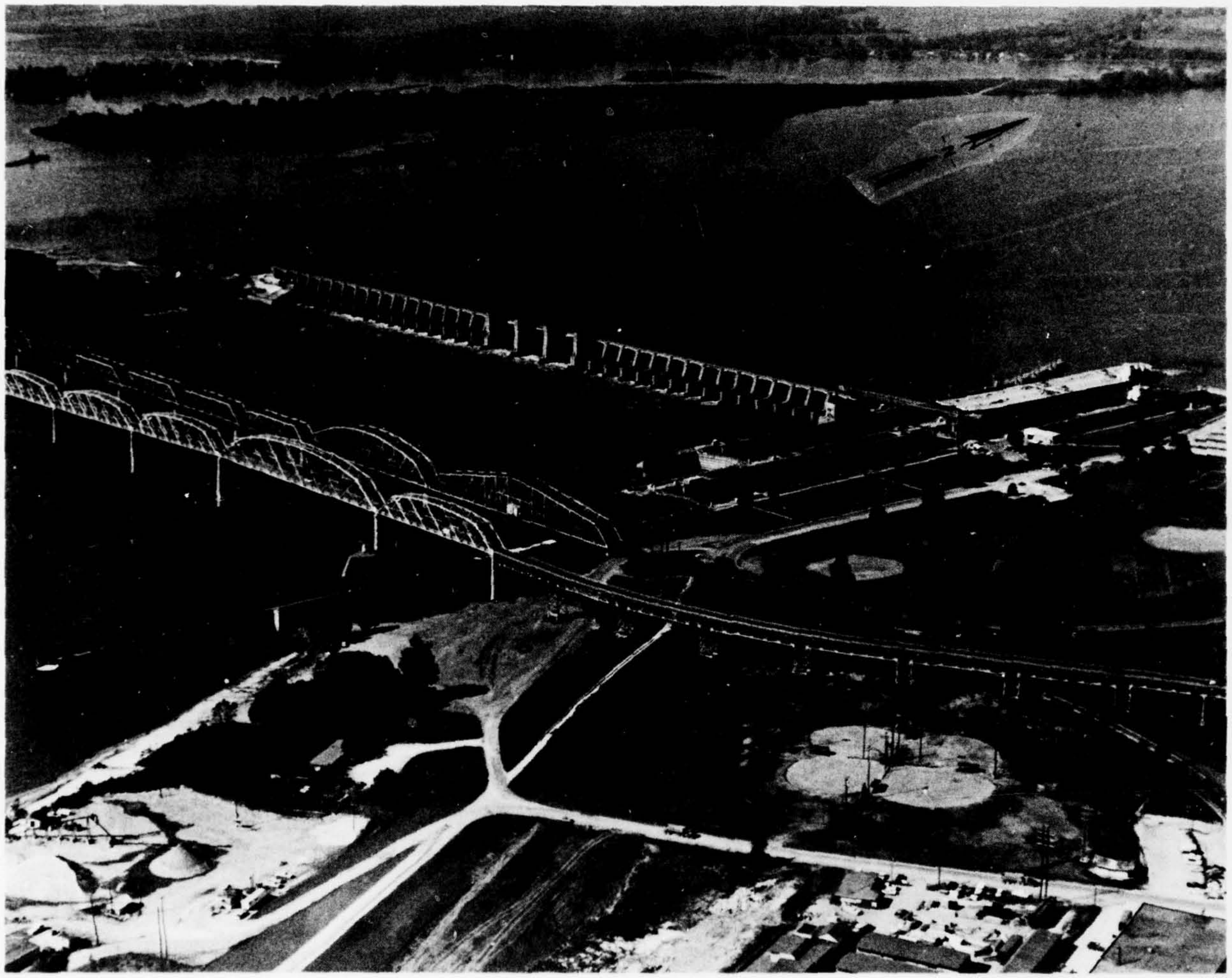

Figure 1. Locks and Dam 26

tailwater. The main lock (test lock) filling and emptying system consists of two 12.5- by 12.5-ft culverts, each having six intake ports located in the upper approach walls followed by a transition into a 14.0-ft-diam inverted horseshoe-type culvert with forty 4- × 5-ft side ports that empty into the lock chamber. The lock is emptied through these culverts and 24 ports in the downstream approach walls. Culvert inflow and outflow are controlled by 12.5- by 12.5-ft conventional tainter valves.

Figure 2. Vicinity map

Purpose and Scope

4. The objective of the U. S. Army Engineer District, St. Louis, is to move traffic through the structure at the fastest and safest speed possible. The primary purpose of the tests, as stated in part above, was to determine the fastest permissible single-valve lock chamber filling (and emptying) that can be tolerated without exceeding the Corps' generally accepted maximum load per hawser of 5 tons.*

5. Experience at the project has shown that during single-valve filling, the barges move transversely into the chamber wall of the operating valve. This is probably caused by the following sequence: (a) flow from the submerged sidewall ports passes across the lock near the chamber floor (Plate 1), (b) strikes the opposite wall and turns upward, and (c) moves back across the lock at a depth shallow enough to cause movement of the barges due to direct pressure and shear.

* Office, Chief of Engineers, Department of the Army, "Hydraulic Design of Navigation Locks," Engineer Manual 1110-2-1602, April 1956, Washington, D. C.

6. Sufficient tests were scheduled to determine what single-valve opening height could be used that would just avoid a single hawser load of 5 tons for the test lift.

PART II: TEST EQUIPMENT AND PROCEDURES

Test Equipment

7. The test equipment described herein includes the transducers, photography, cables, gages, and recording equipment. The measurements and equipment used for each were as follows:

- a. Hawser loads: 50,000-lb load cells
- b. Valve motion: 5-turn continuous potentiometers
- c. Lock water surface: 25-psia pressure transducers
- d. Chamber flow directions and velocities: electromagnetic current meter
- e. Tow movement: timed photographs

Table 1 lists the equipment type, range, and function; the locations are shown in Plate 1.

The 50,000-lb dynamometers (LHU, LHD) used for hawser measurements were calibrated at WES prior to the tests. They were carefully installed in the test hawser lines to avoid changes in calibration. The upstream load cell LHU, ratchet for removing slack, and the hawser are shown in Figure 3.

9. Angular-type potentiometers (LVU, LUD, IVU, IVD) were mounted on the shaft of each valve-lifting drive sprocket to measure valve openings (Figure 4). Prior to the tests, angular rotation of the shafts was calibrated to the corresponding valve movements.

10. Average lock water-surface elevations were monitored continuously during each test. A 25-psia pressure transducer was placed at a known elevation (just below lower pool) on each lock wall (LWL, LWI) as shown in Plate 1. These data were also used in estimating lock chamber transverse water-surface slopes.

11. Transverse and longitudinal velocities were recorded with a Marsh-McBirney Model 711, two-axis, electromagnetic current meter (LFT, LFP) located at the corner of barges A, B, D, and E as shown in Plate 1. The velocity vectors were resolved to determine the actual flow velocity and direction.

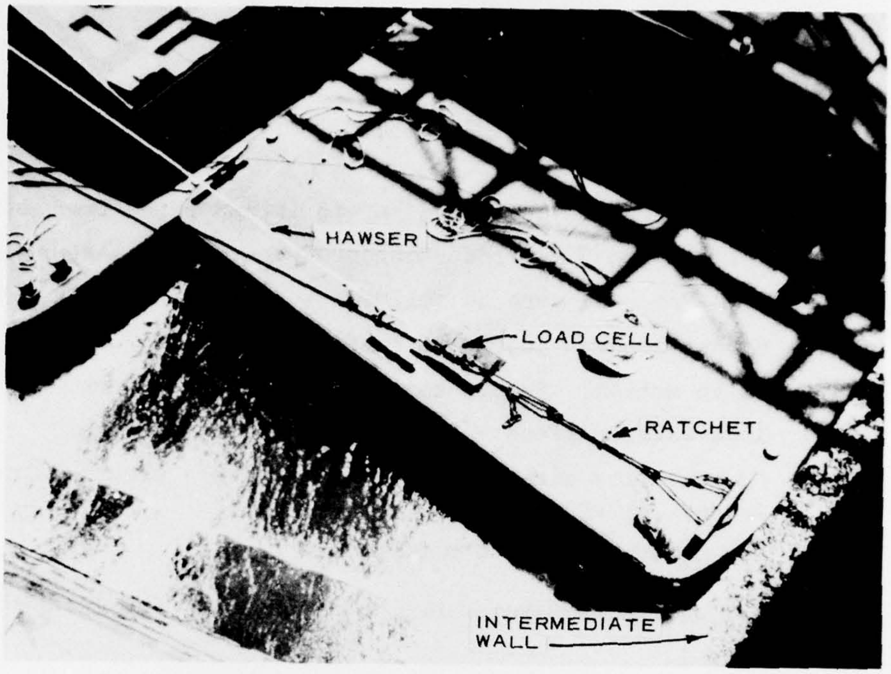

Figure 3. Hawser load cell (LHU) and ratchet at upstream end of tow

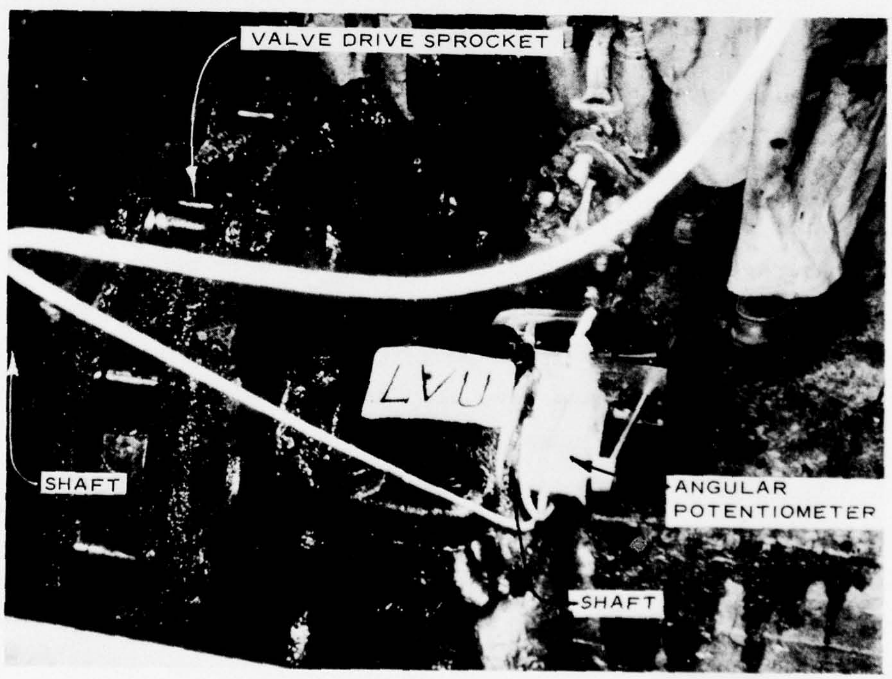

Figure 4. Valve opening measurement instrumentation; land wall, upstream valve (LVU)

12. Timed photographs were made at two locations (Plate 1) during each test to determine direction of tow movement during operating conditions. The cameras were located at either end of the center barge (about 195 ft apart). Two locations were used to determine tow orientation with respect to the lock wall.

13. Cable lengths required for the test program were determined from contract drawings of the project. These lengths were cut and used in the pretest calibration of their corresponding transducers to account for line losses. Table 1 gives the cable length for each transducer.

14. The recording equipment consisted of (a) a WES-fabricated model 01 amplifier to condition the transducer output signal; (b) a Sangamo Sabee 5, 32-channel, frequency-modulated, magnetic tape recorder with a frequency response up to 2.5 kHz at 7.5 ips and 40 kHz at 120 ips; (c) a Century model 541 galvanometer driver to supply higher current to the high-frequency galvanometer; and (d) a CEC model 1-119, 12-in.-chart, oscillograph capable of reproducing 36 channels of data at a paper speed from 0.25 ips to 160 ips at a maximum frequency response of 2500 Hz. Magnetic tape and oscillograph speeds used during the tests were 7.5 ips and 0.04 ips, respectively. Figure 5 shows the equipment setup at the recording station.

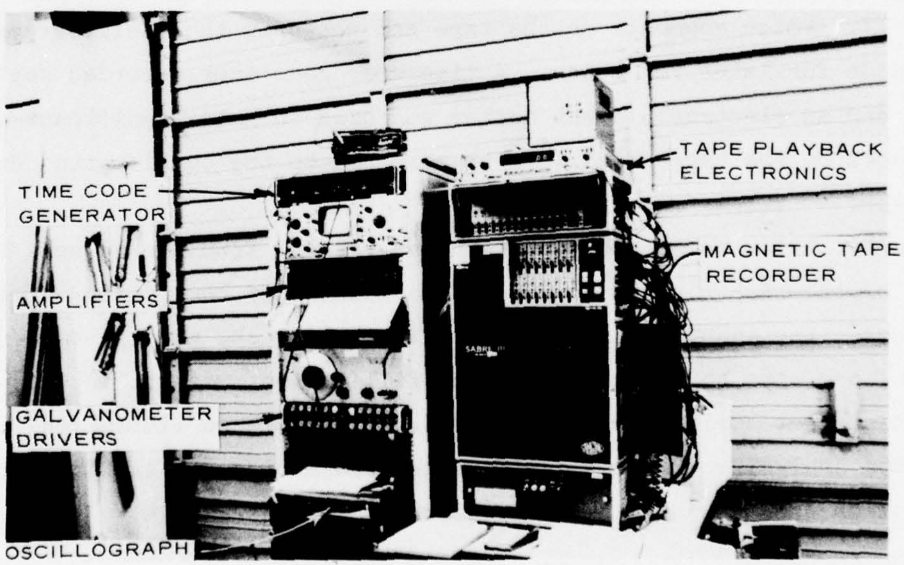

Figure 5. Recording equipment

Test Procedures

15. Six filling tests and one emptying test were conducted on 27 July 1977 (Table 2). The lift during the tests was 20 ft, ±0.2 ft. During each test, a portion of the taped data was transferred to the oscillogram to confirm that the data were being recorded and to make a visual check of the results. Later, each entire test run was transferred to oscillograms for reduction and analysis. Plate 2 presents a typical test trace.

16. Procedures were the same for all tests which consisted of the following (with personnel on station):

- a. Record test number, time, and initial conditions.
- b. Record zero static pressures.
- c. Record step calibrations.
- d. Start recorders.
- e. Raise intermediate wall filling (or emptying) valve to desired opening.
- f. Record data on tape and oscillograph at speeds given above.
- g. Record air and water temperatures and final conditions.
- h. Record step calibrations.

17. Voice comments on the tape and notes on the oscillograms were made for later reference. A time code generator recorded continuously and an electronic event marker was used to note significant occurrences on the tape which were transferred to the oscillograms during playback.

18. Prior to each test, slack was removed from the hawsers by means of the rachet shown in Figure 3. Because of the limited time available, the inability to remove sufficient slack, and the tendency for the new rope to stretch, only one filling test was run in which the barges did not strike the opposite wall. This placed limitations on the data analysis. However, sufficient information was available to accomplish the test objective as presented in paragraph 4.

PART III: TEST RESULTS AND ANALYSIS

Filling Tests

Valve opening

19. The valve openings were designated by time of opening as 10-, 20-sec, etc., valve openings. The corresponding heights of opening were determined and are listed in Table 2. As shown in the table, these times varied from 10 sec (1.79 ft) to 80 sec (fully open, 12.5 ft). For a 20-sec valve (3.43 ft), the maximum hawser load recorded was 5.07 tons at the upstream hawser (LHU). Plate 3 shows that this is the largest valve opening which can be used without exceeding the 5-ton limit discussed in paragraph 4. Because of excessive slack in the lines the results of test 4 were not considered in this determination.

Lock water-surface differential

20. Gravitational forces created by a significant transverse lock water-surface differential would increase (or decrease) the hawser load restraining movement of the barges. For this reason, a continuous lock water-surface differential was determined from pressure transducer measurements described in paragraph 10.

21. With the exception of test 1 there was no significant water-surface differential prior to the barges striking the intermediate wall and/or the hawsers reaching their maximum value. During test 1 there was an initial buildup on the intermediate wall that averaged about 1 ft and lasted for about 1-1/2 min. This differential then subsided to zero and began to build up on the opposite wall. Plate 4 presents the differential magnitude and the wall on which the higher elevation occurred during test 5. (All magnitudes shown in Plate 4 are less than the accuracy limits of the transducers for absolute values, but the trend and relative values are considered to be useful.) Note that the maximum load on the upstream hawser occurred near the time of maximum positive water-surface differential on the land-wall side.

Lock chamber velocities

22. It is known that during single-valve filling, the barges in

the lock will move transversely into the chamber wall of the operating valve. The assumed reason for this is discussed in paragraph 5. An attempt was made to verify the assumption by measuring the near-surface velocity magnitude using equipment and methods discussed in paragraph 11.

23. A large majority of the chamber velocities measured were less than 0.5 fps. Based on the manufacturer's quotations and characteristics of the subject tests, the accuracy of the current meter used in the tests is considered to be quite good at low velocities (± 4 percent of the measurement). The meter was oriented so that transverse (LFT) and longitudinal (LFP) velocity components were measured. From these data the resultant magnitudes and direction were resolved.

24. In all tests the predominant direction of near-surface flow was about $45°$ on the average into the first quadrant as defined in Plate 5. The second most frequent direction was into quadrant II. The magnitude of the velocities was found to be directly proportional to the valve opening. These data seem to support the stated theory that near-surface flows are responsible for moving the barges toward the operating valve wall. Also shown in Plate 5 is a plot of velocities and upstream hawser loads (LHU) recorded during test 5 through the time of maximum load.

Barge movement

25. Timed photographs confirmed that the barges moved from their initial position adjacent to the land wall out toward the intermediate wall. Photos 1 and 2 show, respectively, the movement of the downstream (camera 2, Plate 1) and the upstream (camera 1) measurement points during test 5. Both photographs show that the reference points on the barges move transversely out to a maximum distance within the first two minutes and remain approximately in that position. Movement parallel to the chamber walls was initially downstream, after which the points oscillated about a position upstream of their initial locations.

26. Plate 6 presents a plot of transverse barge movement and hawser load at the upstream station (test 5) and shows that the hawser load peaks and then decays rapidly with time while the barge position

practically remains constant. This may be due to the initial momentum of the moving system being absorbed by the hawser which is stretched taut and thereby prevents a second momentum buildup.

Logarithmic decrement

27. Plates 2 and 6 show that the hawser force oscillations are damped and therefore decay with time. The logarithmic decrement δ, being defined as the natural logarithm of the ratio of successive amplitudes, is a convenient method of expressing the system damping. This is given by the equation:*

$$\delta = \frac{1}{n} \ln \frac{Xo}{Xn} \tag{1}$$

where

Xo = the initial peak amplitude

Xn = the amplitude after n cycles have elapsed

28. Data from the upstream hawser (test 5), were used for a sample calculation. A best-fit line was first calculated because the data do not oscillate about a horizontal line. The value of δ was found to equal 0.87. This information can be used to estimate the number of cycles that will elapse before a given reduction in amplitude is reached for the given equipment and test conditions.

29. During test 5 at time $t = 2.0$ min, the upstream hawser (LHU) stretched 4.5 ft from the initial prestressed condition at time $t = 0$ (Photo 2). This amounted to a length change of 4.1 percent. The hawser load recorded at this time was 6764 lb or 13.5 percent of the rope's tensile strength. The predicted** elongation for the given conditions and rope properties is about 8 percent. Although these values are reasonably close, the difference is probably primarily due to the initial, unaccounted-for stretch caused by the prestressing.

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* W. T. Thomson, "Vibration Theory and Applications," Prentice-Hall, Englewood Cliffs, N. J., 1965.

** J. J. Myers and C. H. Holm, "Handbook of Ocean and Underwater Engineering," McGraw-Hill, N. Y., 1969.

Hawser forces

30. The recorded maximum hawser loads for the filling tests varied from 1.21 to 6.27 tons (Table 2). Increasing the valve opening did not always increase the hawser loads. This occurred because of the difficulty in removing sufficient slack from the lines to prevent the barges from striking the opposite wall as discussed in paragraph 18.

31. The only run in which the barges did not strike the opposite wall was test 5. For this reason the majority of the report analysis was made using the data from this test. The valve was opened for 20 sec (3.43 ft) and the resultant upstream and downstream loads were 5.07 and 4.89 tons, respectively. These loads are very close to the desired limiting load of 5 tons. Therefore, the initial valve opening of 20 sec for single-valve filling is recommended. Even though the barges struck the wall at a valve opening of 25 sec (4.20 ft), both hawser loads exceeded 5 tons, thereby confirming that the 20-sec valve was the maximum which should be allowed.

Filling time

32. Because of heavy traffic at Locks and Dam 26, lockage time must be held to a minimum. On 13 June 1977, the St. Louis District and WES personnel determined that the lock would fill in 16 min by fully opening the intermediate wall valve only, the lift being 19.70 ft. Smaller valve openings would obviously increase this time of filling. To minimize this additional filling time the following procedure is recommended.

- a. Open the intermediate wall valve for 20 sec (3.43 ft).
- b. Note visually when the hawsers have been fully stretched (less than 2 min, see Table 2), i.e., barge-to-wall distances stabilize.
- c. Fully open valve at maximum speed.

33. A mathematical model* has been developed at WES for predicting lock filling times and was utilized in preparing the Lock 26 filling

* Hebler, M. T., and Neilson, F. M., "Lock Filling and Emptying--Symmetrical Systems," Miscellaneous Paper H-76-13, June 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

times required for different heads and valve conditions. Physical characteristics and the recorded filling time discussed above were used as inputs to the model. Table 3 presents the times to fill at different gate openings which remained constant throughout the filling period as well as the times required using the above recommended procedures. As an example, using the latter procedure, a savings of 23.3 min (56 percent) would be realized at a head of 20 ft. The program does not consider indeterminant leakage through the values and miter gates what would affect the total filling period. The information presented should, however, be useful for relative comparisons.

Emptying Test

34. One emptying test (No. 7, Table 2) was conducted. The intermediate wall valve was opened fully and the chamber allowed to empty at the maximum rate under the given conditions. The maximum hawser load recorded was 1.06 tons. The lock chamber velocities and water-surface differential data were insignificant. For these reasons, no restrictions on single-valve emptying are recommended.

PART IV: CONCLUSIONS

35. The following determinations, conclusions, and recommendations result from analyses of the Lock 26 tests at the existing lift and given test procedures:

a. The barges move toward the chamber wall of the operating valve during lock filling.

b. The near-surface flow direction is predominantly upstream toward the intermediate wall and is responsible for the barge movement.

c. For filling, initial valve opening should be limited to approximately 3.4 ft (20 sec). This will limit the maximum hawser load to approximately 5 tons. After the hawsers have been fully stretched the valve could be opened fully at maximum speed.

d. For emptying, the valve may be fully opened at maximum speed without approaching the 5-ton limit.

Table 1

Lock 26 Instrumentation

		Instrument		
Measurement	Code*	Type	Range	Cable Length ft
Upstream hawser load	LHU	Baldwin-Lima-Hamilton Load Cell	50,000 lb	435
Downstream hawser load	LHD	Baldwin-Lima-Hamilton Load Cell	50,000 lb	1056
Land-wall filling valve motion	LVU	Instrument Angular Potentiometer	5-turn continuous	300
Intermediate wall filling valve motion	IVU	Instrument Angular Potentiometer	5-turn continuous	600
Land-wall emptying valve motion	LVD	Instrument Angular Potentiometer	5-turn continuous	820
Intermediate wall emptying valve motion	IVD	Instrument Angular Potentiometer	5-turn continuous	1150
Land-wall lock water surface	LWL	CEC 4-312 Pressure Transducer	0-25 psia	591
Intermediate wall lock water surface	LWI	CEC 4-312 Pressure Transducer	0-25 psia	800
Transverse lock flow	LFT	Marsh-McBirney Current Meter T11	0-10 fps	600
Longitudinal lock flow	LFP	Marsh-McBirney Current Meter T11	0-10 fps	600

* See Plate 1 for location.

Table 2

Lock 26 Hawser Test Results

27 July 1977

Test No.	Fill or Empty	Valve Open Duration sec	Final Valve Opening ft	Time of Max Hawser Load sec US/DS	Max Hawser Load tons US/DS	Load Period sec US/DS	Upper/Lower Pool Elevation ft msl
1*	F	15 open 45 hold (repeat)	9.79	54/90	2.84/2.18	50/50	418.80/398.99
2	F			Aborted run (wrong valve opened)			
3*	F	10	1.79	50/68	1.99/1.21	**	418.70/398.69
4*	F	30	5.00	42/59	3.23/2.67	50/12	
5	F	20	3.43	52/98	5.07/4.89	**	
6*	F	25	4.20	46/70	6.27/5.32	50/33	
7	E	Opened full	12.50	88/112	0.54/1.06	**	

* Test tow struck intermediate wall.
** Very large period.

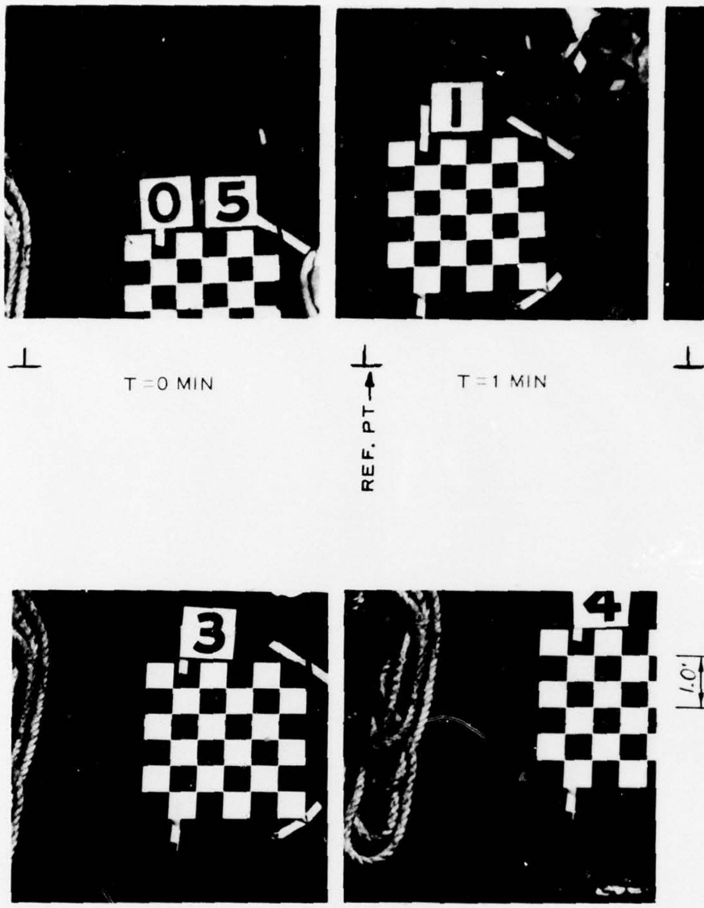
Table 3

Lock 26 Calculated Single Valve, Chamber Filling Times

Initial Valve Opening Time sec/min	Initial Valve Opening ft	Hold Time min	Remaining Valve Opening Time min	Final Valve Opening ft	Total Time min
		15-ft Head			
10/0.17	1.79	--	--	1.79	66.0
10/0.17	1.79	2.0	1.16	12.50	16.7
20/0.33	3.43	--	--	3.43	36.5
20/0.33	3.43	2.0	1.00	12.50	16.3
25/0.42	4.20	--	--	4.20	30.5
25/0.42	4.20	2.0	0.92	12.50	16.2
30/0.50	5.00	--	--	5.00	26.0
30/0.50	5.00	2.0	0.83	12.50	16.0
		20-ft Head			
10/0.17	1.79	--	--	1.79	76.0
10/0.17	1.79	2.0	1.16	12.50	19.0
20/0.33	3.43	--	--	3.43	42.0
20/0.33	3.43	2.0	1.00	12.50	18.7
25/0.42	4.20	--	--	4.20	35.0
25/0.42	4.20	2.0	0.92	12.50	18.5
30/0.50	5.00	--	--	5.00	30.0
30/0.50	5.00	2.0	0.83	12.50	18.3
		24-ft Head			
10/0.17	1.79	--	--	1.79	83.5
10/0.17	1.79	2.0	1.16	12.50	20.5
20/0.33	3.43	--	--	3.43	46.0
20/0.33	3.43	2.0	1.00	12.50	20.2
25/0.42	4.20	--	--	4.20	38.5
25/0.42	4.20	2.0	0.92	12.50	20.0
30/0.50	5.00	--	--	5.00	33.0
30/0.50	5.00	2.0	0.83	12.50	19.8

Note: Time to fully open valve 12.5 ft: 80 sec (1.33 min).

RIVER
FLOW



T = 0 MIN

REF. PT

T = 1 MIN

T = 2 MIN

T = 3 MIN

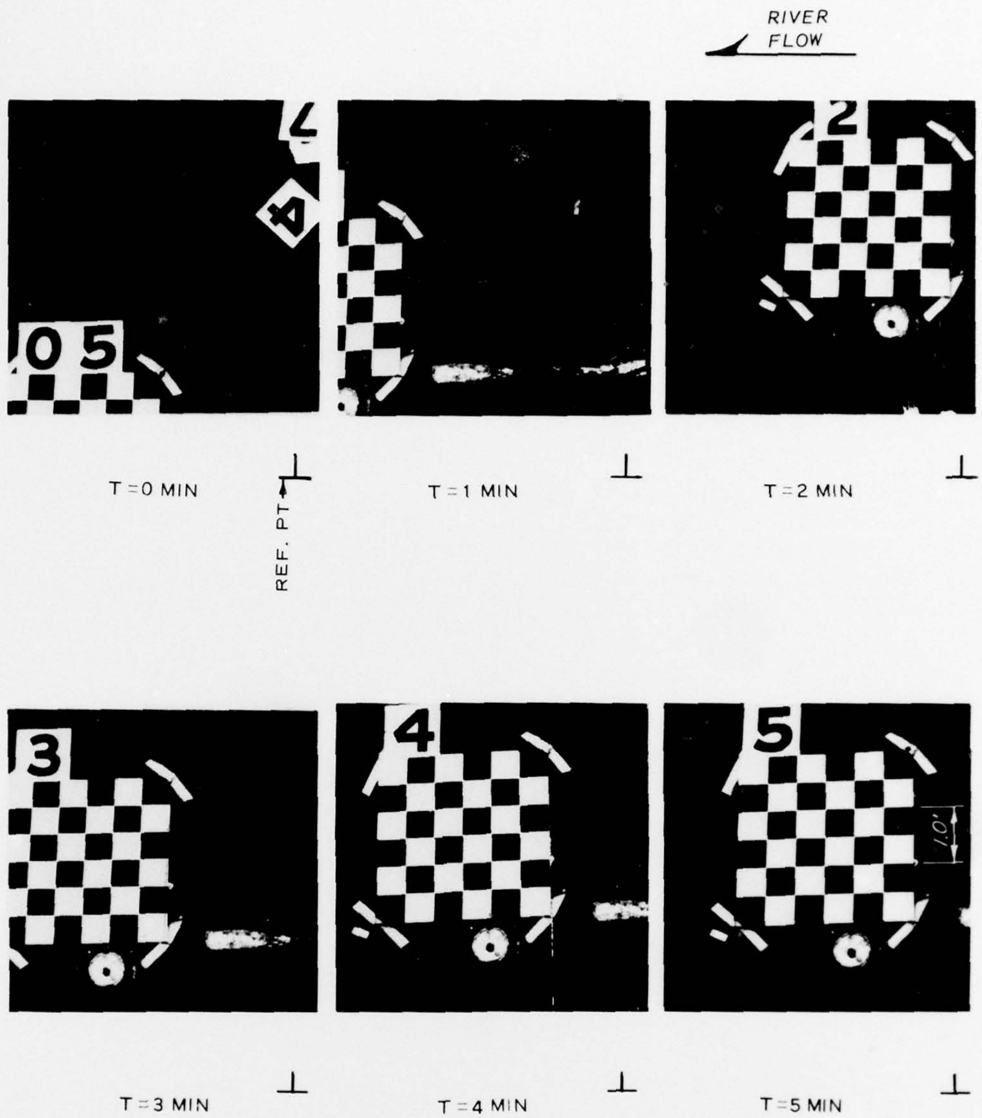
T = 4 MIN

SEE PLATE 1

NOTE: MAXIMUM HAWSER
LOAD (LHD) OCCURRED
AT T = 1.63 MIN

BARGE MOVEMENT
TEST 5, CAMERA 2 (D.S.)

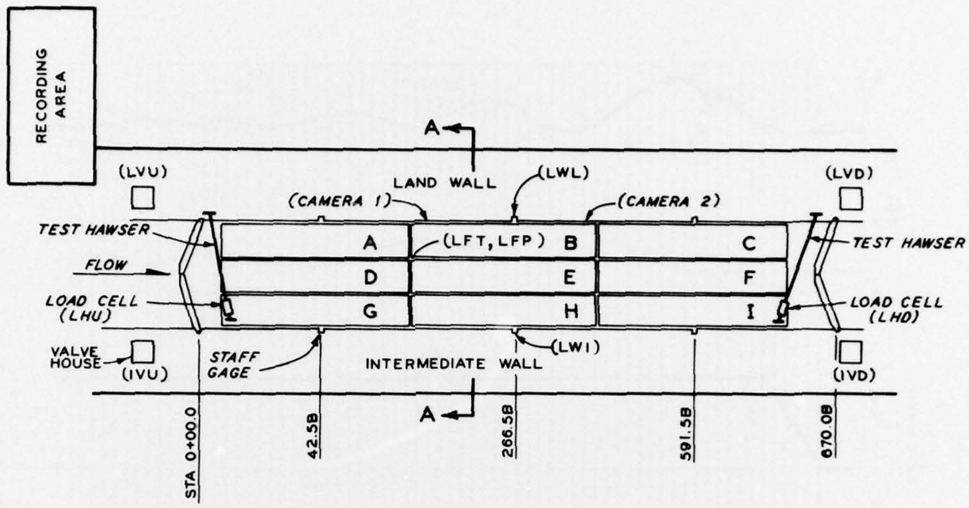
PHOTO 1



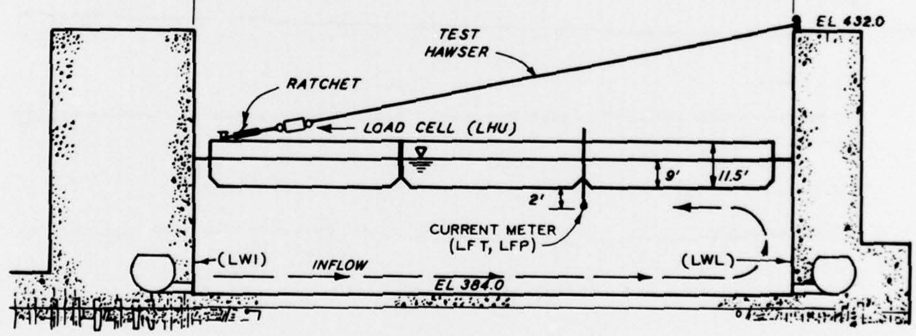
NOTE: MAXIMUM HAWSER
LOAD (LHU) OCCURRED
AT T = 0.87 MIN

BARGE MOVEMENT
TEST 5, CAMERA 1 (U.S.)

PHOTO 2



PLAN

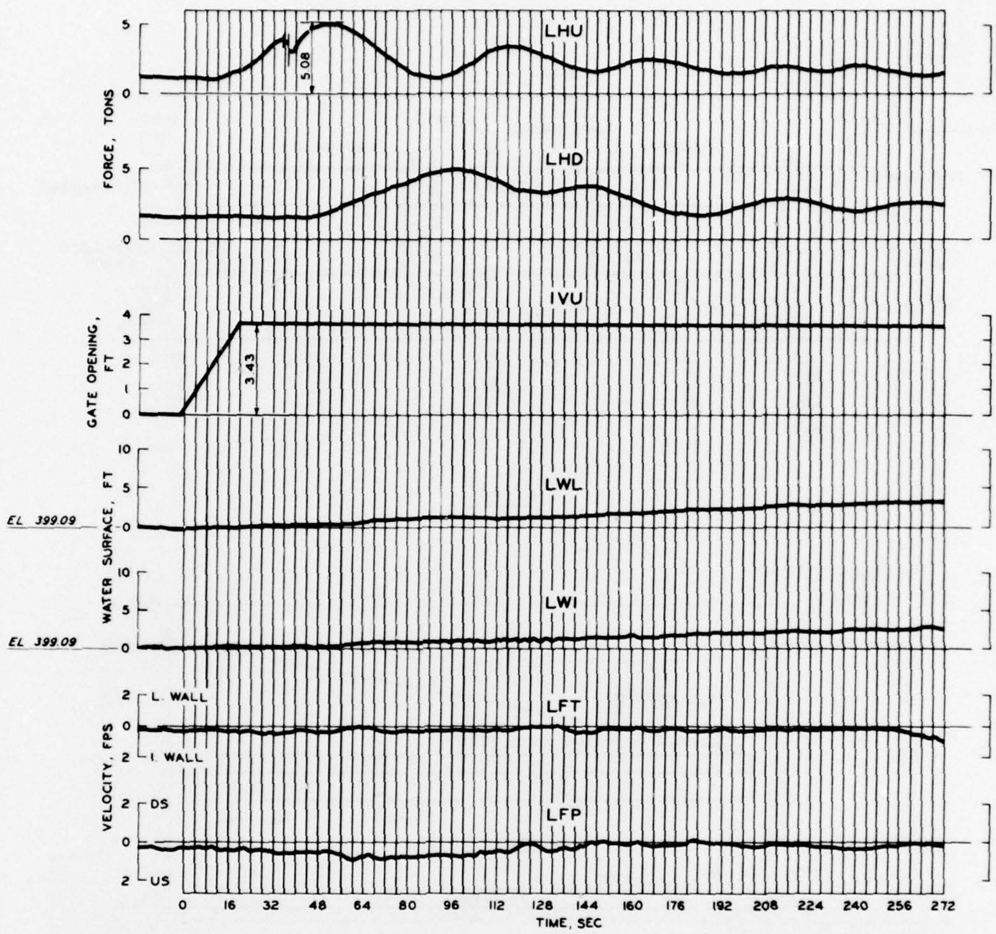


SECTION A-A

NOTES:
1. BARGE SIZE 35' X 195'
2. BARGE A EMPTY, WT APPROX 500 TONS
3. BARGES B-I LOADED WITH COAL APPROX TOTAL WT EACH: 1900 TONS

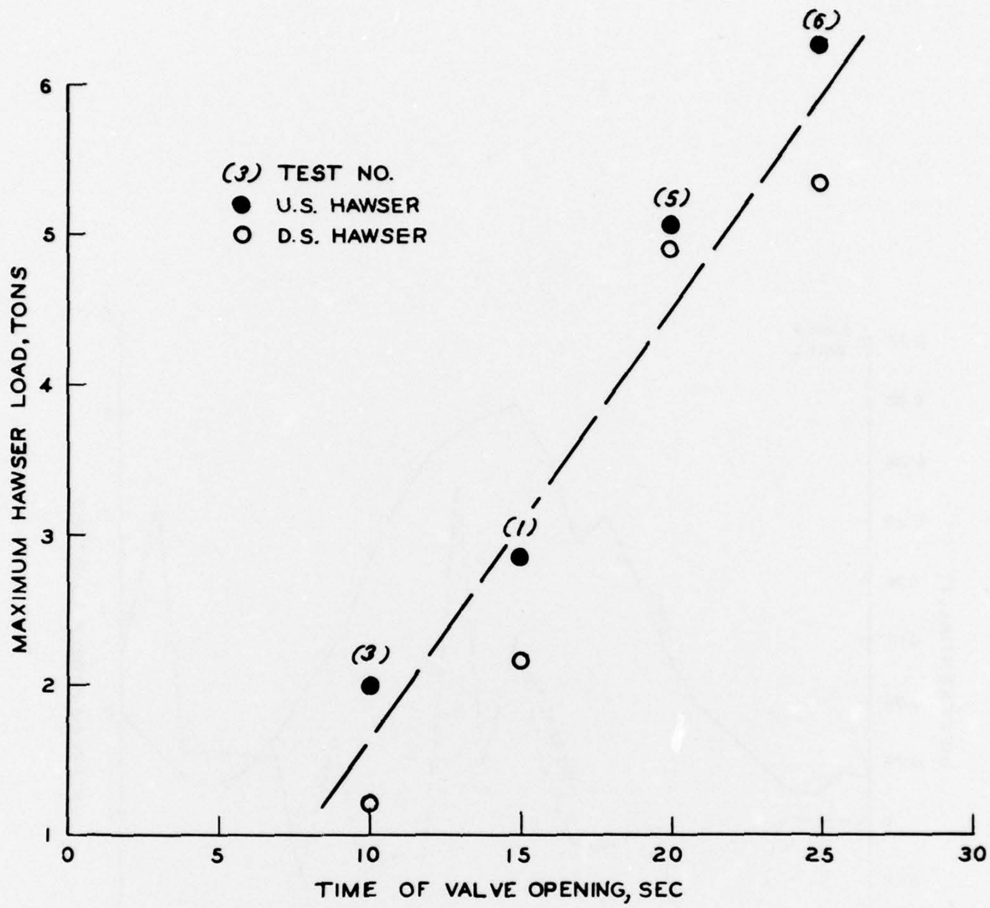
HAWSER TEST INSTRUMENTATION

MAIN LOCK



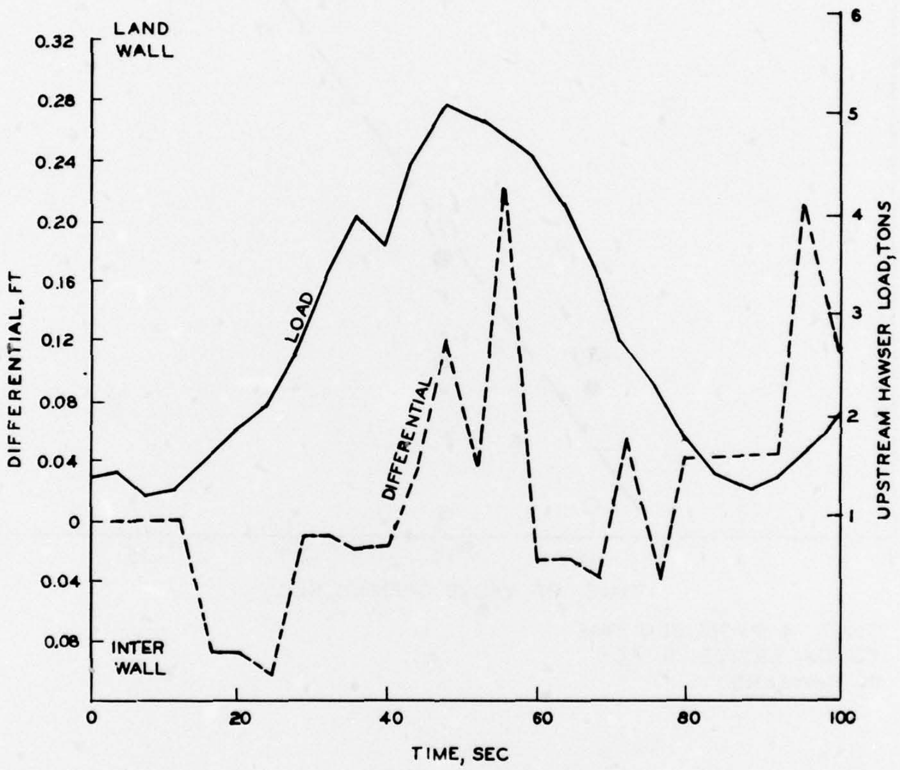
PROTOTYPE TESTS

TEST 5, FILLING



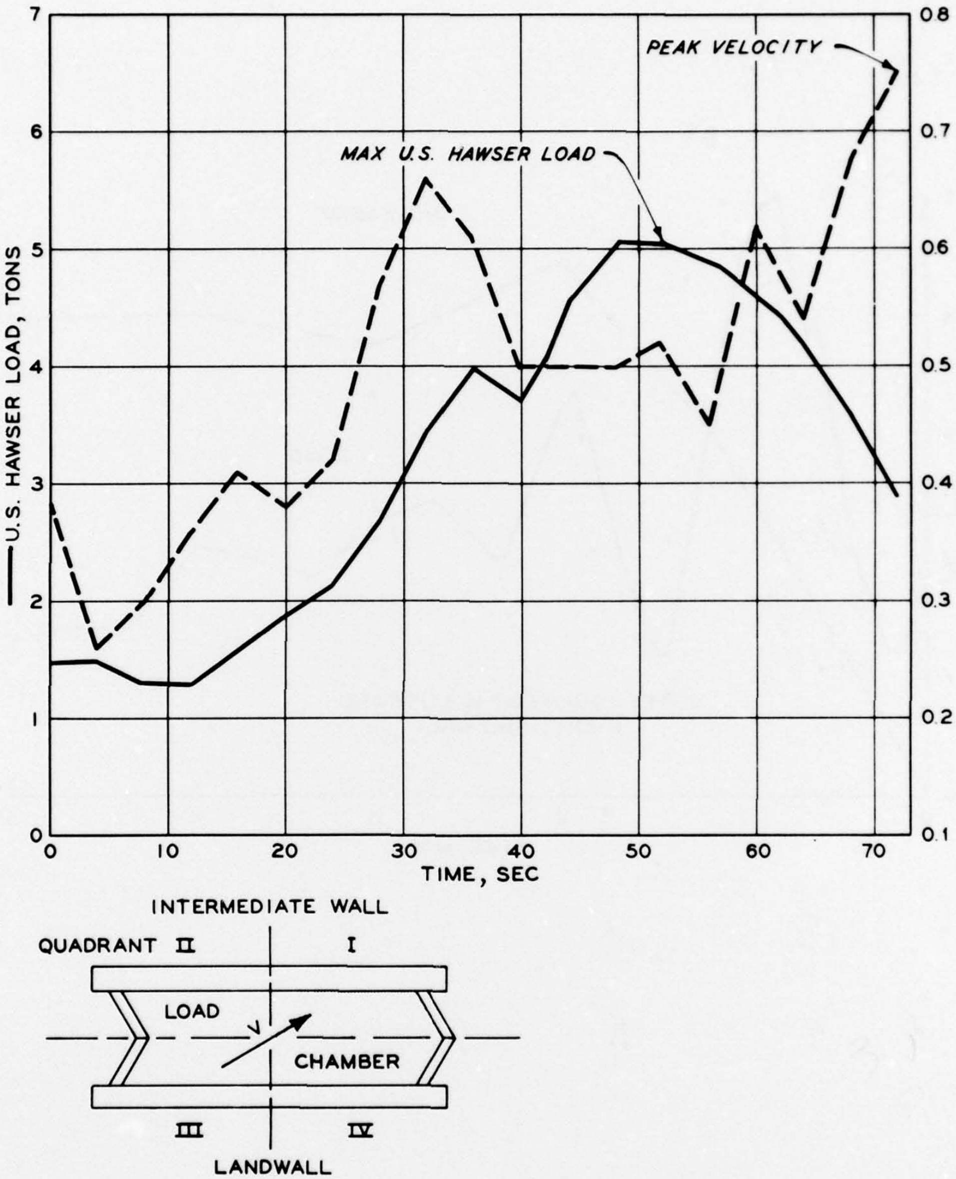
NOTE: TEST 4 EXCLUDED DUE TO EXCESSIVE SLACK IN HAWSERS.

HAWSER LOADS VERSUS SINGLE VALVE OPENING TIME



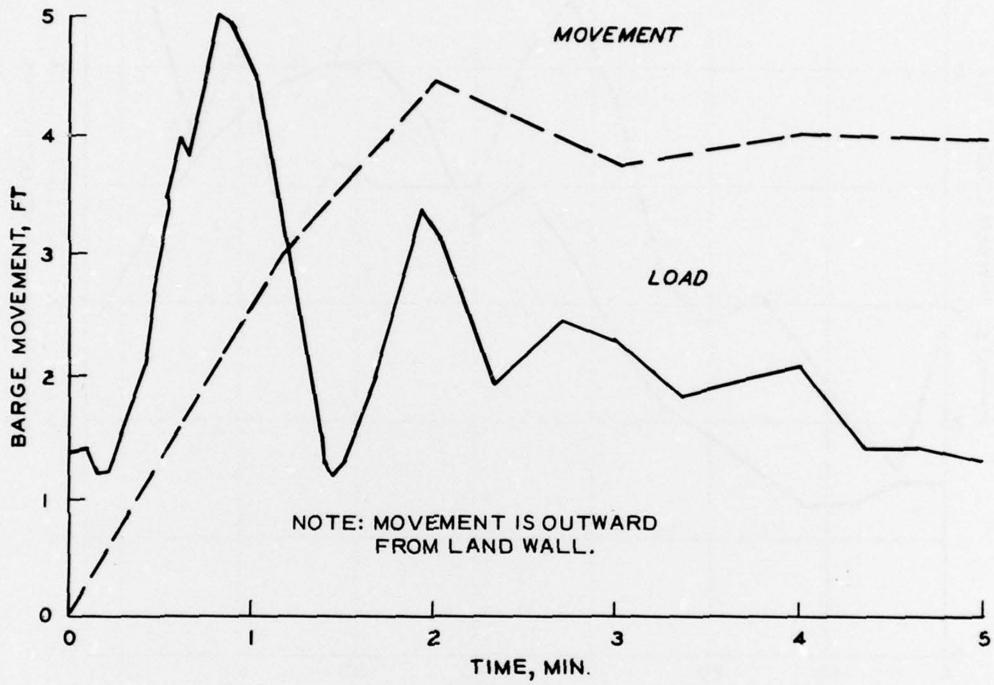
HAWSER LOAD AND LOCK CHAMBER
WATER-SURFACE DIFFERENTIAL

UPSTREAM END OF TOW
TEST 5



HAWSER LOAD AND
CHAMBER VELOCITY

UPSTREAM END OF TOW
TEST 5



HAWSER LOAD AND
BARGE POSITION
UPSTREAM END OF TOW
TEST 5

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Hart, Ellis Dale

Single-valve prototype tests, main lock, Locks and Dam 26, Mississippi River, Alton, Illinois / by E. Dale Hart. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

18, [2] p., 6 leaves of plates : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; H-78-10)

Prepared for U. S. Army Engineer District, St. Louis, St. Louis, Missouri.

Includes bibliographical references.

1. Lock and Dam No. 26, Mississippi River. 2. Lock filling and emptying systems. 3. Prototype tests. I. United States. Army. Corps of Engineers. St. Louis District. III. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; H-78-10.

TA7.W34m no.H-78-10